

# Overview of NASA Glenn Research Center's Communications and Intelligent Systems Division

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Presented to:

Professor Warwick Bowen

Program Manager, Centre for Engineered Quantum Systems  
School of Mathematics and Physics, University of Queensland

Brisbane, Queensland, 4072, Australia

# Abstract

The Communications and Intelligent Systems Division provides expertise, plans, conducts and directs research and engineering development in the competency fields of advanced communications and intelligent systems technologies for application in current and future aeronautics and space systems.

# Research and Engineering Directorate Leadership Team

**Deputy Director of  
Research and Engineering (L)**



Dr. Marla Pérez-Davis

**Director of  
Research and Engineering (L)**



Dr. Rickey J. Shyne

**Associate Director of  
Research and Engineering (L)**



Maria Babula

**Chief Engineer  
Office (LA)**



Richard T. Manella

**Management Support  
and Integration Office (LB)**



Kathy K. Needham

**Communications and Intelligent  
Systems Division (LC)**



Dawn C. Emerson

**Power  
Division (LE)**



Randall B. Furnas

**Materials and Structures  
Division (LM)**



Dr. Ajay K. Misra

**Systems Engineering and  
Architecture Division (LS)**



Derrick J. Cheston

**Propulsion  
Division (LT)**

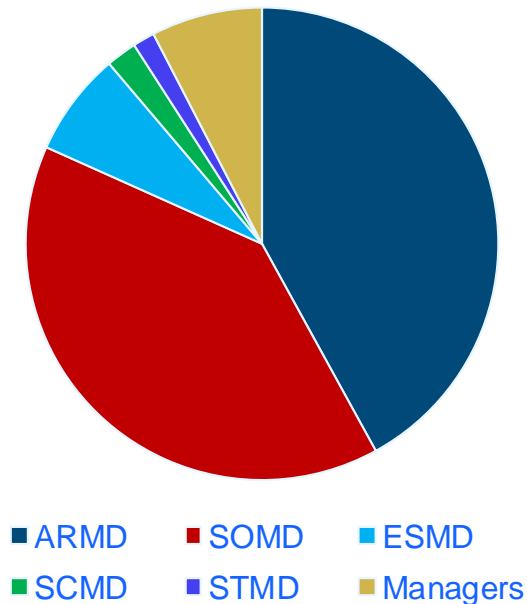


Dr. George R. Schmidt

# Communications and Intelligent Systems Division (LC)

Provides expertise, plans, conducts and directs research and engineering development in the competency fields of advanced communications and intelligent systems technologies for application in current and future aeronautics and space systems.

## LC Support to Mission Directorates



## LC Competency Elements:

### Space Communications (SpaceComm) & Aeronautical Communications (AeroComm)

Expertise:

- Networks & Architectures
- Information & Signal Processing
- Advanced High Frequency
- Optical Communications

### Intelligent Systems – Cross-Cutting Competencies

Expertise:

- Optics and Photonics
- Smart Sensor Systems
- Instrumentation- Electronic
- Controls- Dynamic System Modeling and Controls

# Communications and Intelligent Systems Division (LC)

123 FTE  
58 WYE

## Communications and Intelligent Systems Division (LC)

Ms. Dawn C. Emerson

Deputy: TBD, Dr. Félix A. Miranda- Acting

Communications ST: Dr. Robert R. Romanofsky

### Architectures, Networks and Systems Integration Branch

LCA/Dave Buchanan, Denise Ponchak  
27 FTE (1 Ph.D, 22 MS, 4 BS), 20 WYE

### Intelligent Control and Autonomy Branch

LCC/Dr. Sanjay Garg  
20 FTE (5 Ph.D, 10 MS, 2 BS), 11 WYE

### Advanced High Frequency Branch

LCF/Dr. Felix Miranda  
19 FTE (7 Ph.D, 9 MS, 3 BS), 4WYE

### Information and Signal Processing Branch

LCI/Gene Fujikawa  
18 FTE (4 Ph.D, 10 MS, 4 BS), 8 WYE

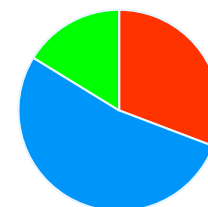
### Optics and Photonics Branch

LCP/Dr. George Baaklini  
20 FTE (9 Ph.D, 10 MS, 1 BS), 6 WYE

### Smart Sensors and Electronics Systems Branch

LCS/Dr. Larry Matus  
16 FTE (10 Ph.D, 4 MS, 2 BS), 8 WYE

## Education

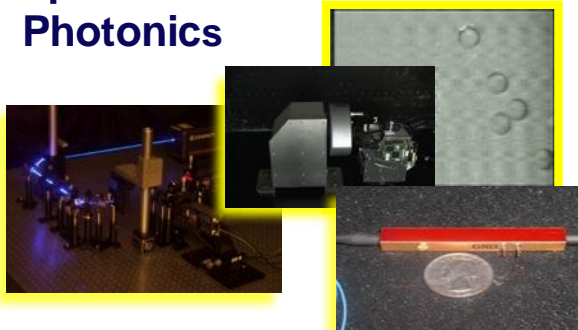


■ PhD ■ MS ■ BS



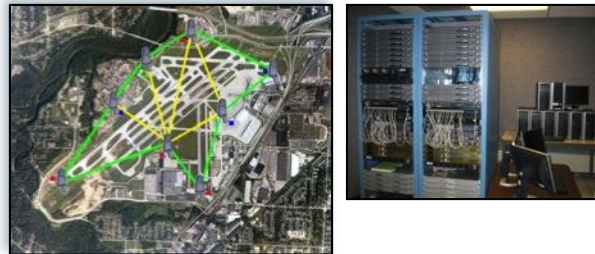
# Communications and Intelligent Systems Division (LC)

## Optics and Photonics



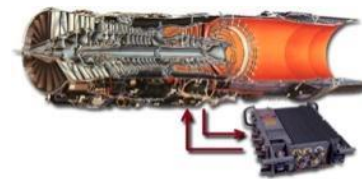
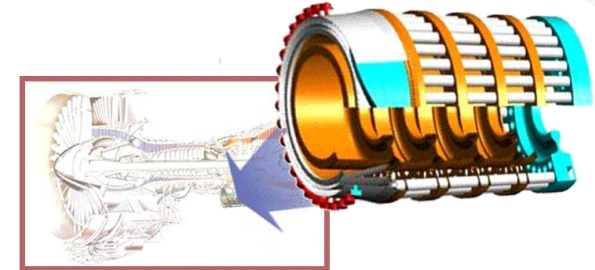
Optical Instrumentation  
Optical Communications  
Health Monitoring

## Architectures, Networks and Systems Integration



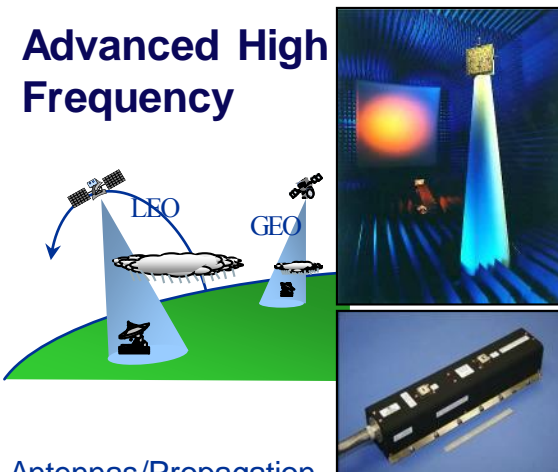
Communications Architectures  
Modeling and Simulation/Tech Demos  
Spectrum and Link Analysis

## Intelligent Control and Autonomy



Intelligent Controls  
Dynamic Modeling  
Health Management

## Advanced High Frequency



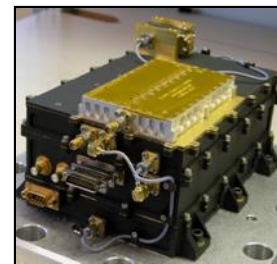
Antennas/Propagation  
RF Systems and Components  
3-D Electromagnetic Modeling

## Smart Sensors and Electronics Systems



Thin Film Physical Sensors  
High Temp/Harsh Environment Focus  
Wireless Technologies

## Information and Signal Processing

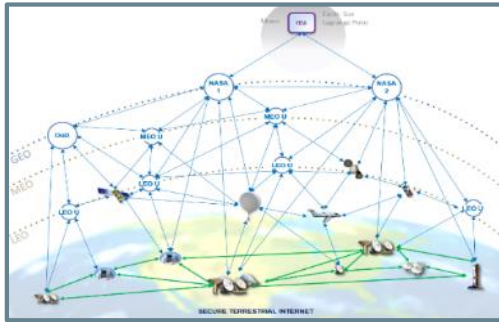


Radio Systems – SDRs, Cognitive  
Bandwidth and Power-Efficiency  
Waveform Development



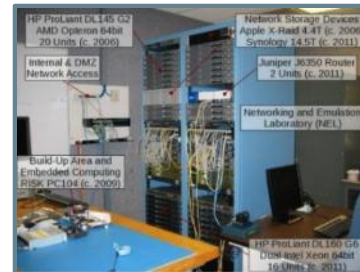
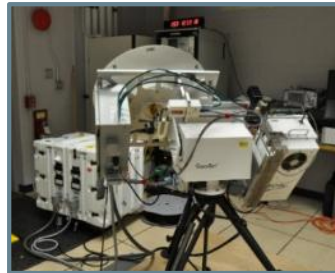
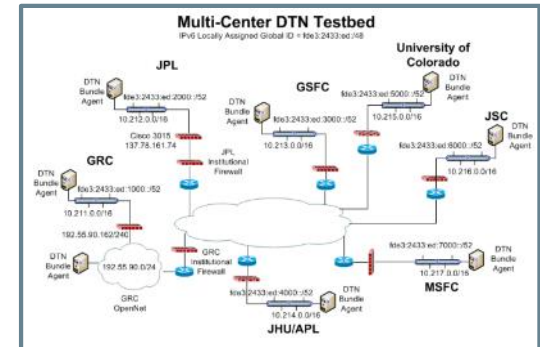
# Additional Information LC Branches

# Architectures, Networks and Systems Integration Branch (LCA)



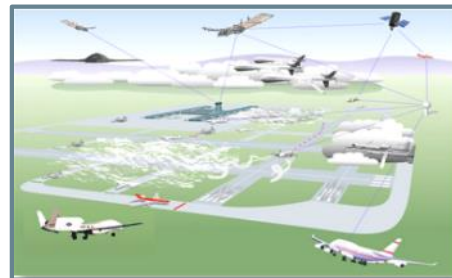
## Communications Systems

- Systems engineering of future SCA<sup>2</sup> Integrated Network Architecture.
- Requirements decomposition, systems definition, development, hardware and software build up, test and delivery of Space Network compatibility test unit including TDRS signal simulator.



## Aeronautical Communications

- Includes air-to-air, air-to-ground, and ground-based mobile wireless communications, information networking, navigation and surveillance research, technology development, testing and demonstration, advanced concepts and architectures development, and national and international technology standards development.



## Network Research

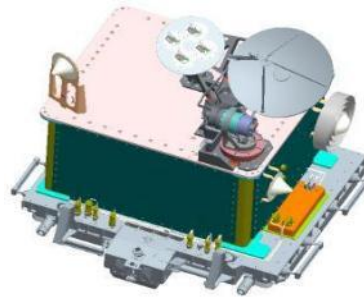
- Development of network components, design of network layers and networked systems architectures. Emphasis is on secure wireless mobility, protocol characterization and development, requirements definition, and flight software/hardware component assessment. Also includes "virtual" mission operations.



# Information and Signal Processing Branch (LCI)

## LCI Overview

Conducts research and technology development of information and signal processing methods and approaches of digital communications systems for aerospace applications. Emphasis on software-defined and cognitive radios; open SDR architectures and waveform development; position, navigation and timing methods; spectrum and power efficient techniques; reconfigurable microelectronic devices



SCaN Testbed

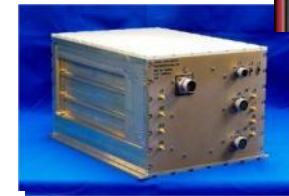


## Focus Areas

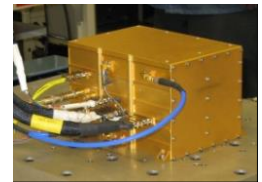
- Software-Defined and Cognitive Radios
  - Space Telecommunications Radio System (STRS)
  - STRS-compliant Hardware and Software
  - SDR Waveform Development
  - Digital Core for RF/Optical Terminal
- High Speed Signal Processing
  - Computer Modeling and Simulation Tools
  - Wireless and Microelectronic Devices for Communications
- Advanced Exploration Systems
  - Integrated Audio/Microphone Arraying
  - EVA Radio Development
  - Surface Navigation
- SCan Testbed Flight Radio Experiments and Demonstrations
  - GPS Navigation and Timing
  - Ka-Band, Bandwidth-Efficient, High Rate Waveform
  - S- and Ka-Band IP Networking and Routing
  - Adaptive Modulation and Coding for Cognitive Radio

## Facilities/Labs

- Software-Defined and Cognitive Radio Technology Development Laboratory
- Digital Systems and Signal Processing Lab
- EVA Radio and Integrated Audio Lab
- SCan Testbed on ISS Available for Experimenters



Software Defined Radios



Extra-Vehicular Activity (EVA) Radio



AES/EVA Integrated Audio



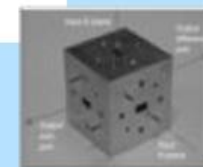
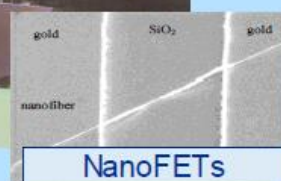
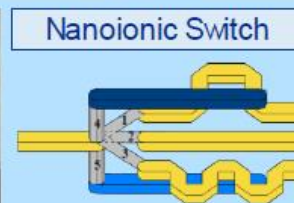
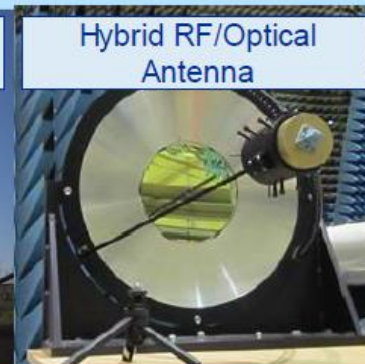
iROC Flexible Digital Core



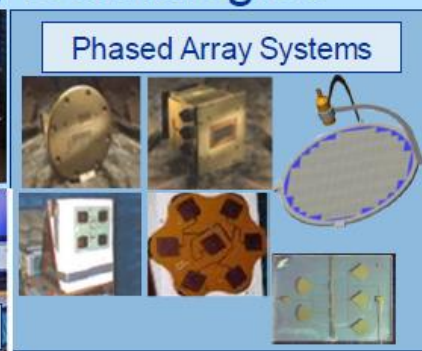
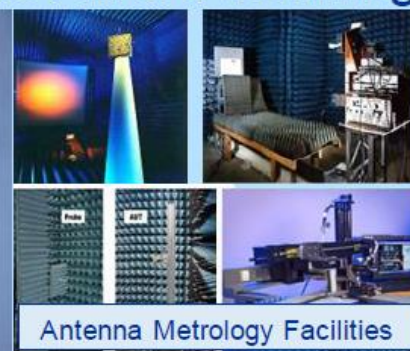
# Advanced High Frequency Branch (LCF)

## Branch Overview

- Conducts research and technology development, integration, validation, and verification at frequencies extending up to the terahertz region in the areas of semiconductor devices and integrated circuits, antennas, power combiners, frequency and phase agile devices for phased arrays, and radio wave propagation through Earth's atmosphere, in support of NASA space missions and aeronautics applications.
- R&D is conducted in-house and also in collaboration with academia and industry to develop low mass, small size, high power and efficiency traveling-wave tube amplifiers, solid state power amplifiers; novel antenna technologies (e.g., wideband antennas, hybrid antennas (i.e., RF/Optical), ground stations, among others.
- The Branch supports development of advanced technologies such as superconducting quantum interference filter (SQIF) for ultra-sensitive receivers and Ka-band multi-access arrays for NASA's next generation space communications.
- Facilities include planar and cylindrical near-field, far-field and compact antenna ranges, cryogenic microwave and millimeter-wave device and circuit characterization laboratory, high power amplifier characterization laboratory, radio wave propagation laboratory, and clean room facilities.
- Semiconductor device modeling and high frequency circuit simulation, fabrication, and integration facilities are also available.



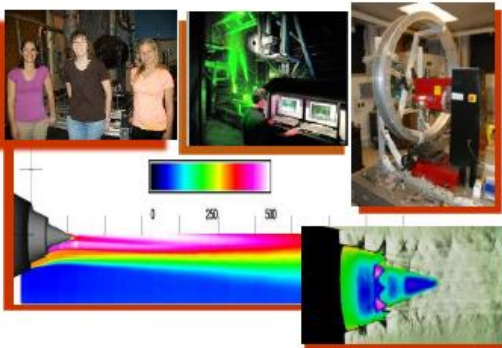
## R&D 100 Award Winning Technologies





# Optics and Photonics Branch (LCP)

## Optical Instrumentation



<http://www.grc.nasa.gov/WWW/Optinstr/>

- Our data and instrumentation help designers understand the fundamental physics of new systems, validate aeronautics computational and life models, and improve space optical communications for human and robotic explorations.

- Our data leads to improved designs, validation and verification of systems performances, increased communications, safety and security and reduced design cycle times for many of the core technologies developed at Glenn and across NASA.

## Photonics and Health Monitoring



## Optical Communications



### Mobile and Remote Sensing

- On-Orbit Solar Cell Characterization MISSE 5-8; TACSAT- 4;
- Hyperspectral Imaging
- Mobile Sensing Platforms

### Communications

- Communications over power lines
- Communications Interface Boards
- High Data Rate

### Health Monitoring

- Microwave Blade Tip Clearance
- Self diagnostic Accelerometer
- Fiber optics sensors
- Morphology dependent resonance
- Phosphor Thermography
- Capacitance & piezo patches sensors
- Wireless and wired techniques

## Flow/Noise Diagnostics

- Particle imaging Velocimetry (PIV)
- Background Oriented Schlieren
- Rayleigh Scattering
- PIV Tomography
- Combustion diagnostics
- Raman Diagnostics (Species, T)
- Plasma generation

## Surface Diagnostics

- Temperature Sensitive Paint
- Pressure Sensitive Paint
- Stress Sensitive Film

## Engine Icing

- Light Extinction Tomography
- Light Extinction Probes
- Raman Spectroscopy
- Impedance Sensor

## Free Space Communications

- Optical Teletennas
- Beaconless Pointing Systems
- High Data Rate for Deep Space & Near Earth

## Secure Quantum Communications

- Quantum Entanglement
- Pulsed photon Pairs
- Quantum Illumination
- Quantum Key Distributions



# Smart Sensors and Electronics Systems Branch (LCS)

## Description

Conducts research and development of adaptable instrumentation to enable intelligent measurement systems for ongoing and future aerospace propulsion and space exploration programs. Emphasis is on smart sensors and electronics systems for diagnostic engine health monitoring, controls, safety, security, surveillance, and biomedical applications; often for high temperature/harsh environments.



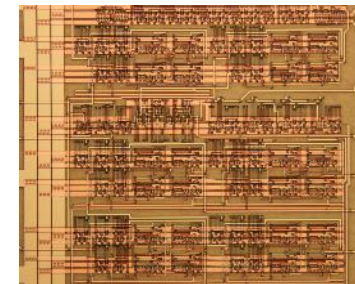
Microsystems Fabrication Facility

## Focus Areas

- Silicon Carbide (SiC) - based electronic devices
  - Sensors and electronics for high temp (600°C) use
  - Wireless sensor technologies, integrated circuits, and packaging
- Micro-Electro-Mechanical Systems (MEMS)
  - Pressure, acceleration, fuel actuation, and deep etching
- Chemical gas species sensors
  - Leak detection, emission, fire and environmental, and human health monitoring
- Microfabricated thin-film physical sensors
  - Temperature, strain, heat flux, flow, and radiation measurements
- Harsh environment nanotechnology
  - Nano-based processing using microfabrication techniques
  - Smart memory alloys and ultra low power devices

## Facilities/Labs

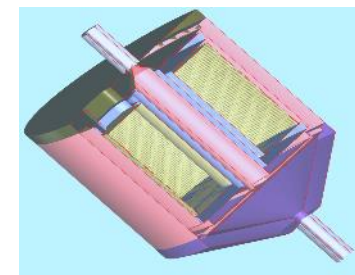
- Microsystems Fabrication Facilities
  - Class 100 Clean Room
  - Class 1000 Clean Room
- Chemical vapor deposition laboratories
- Chemical sensor testing laboratories
- Harsh environment laboratories
  - Nanostructure fabrication and analysis
  - Sensor and electronic device test and evaluation



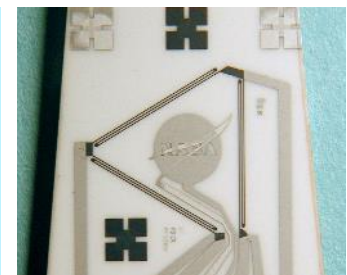
SiC Signal Processing



Chemical Gas Sensors



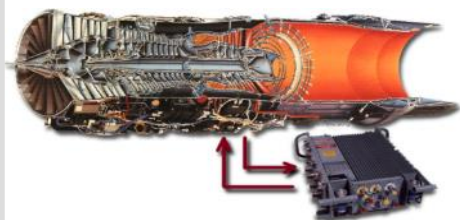
MEMS Fuel Actuation



Thin Film Physical Sensors

# Intelligent Control and Autonomy Branch (LCC)

## Propulsion Controls



### Active Combustion Control

Control of Thermo-acoustic Instability  
High Bandwidth Fuel Actuation

### Advanced Control Architecture

Distributed Engine Control  
Hardware-in-the-loop Test-bed

### Intelligent Engine Control

Enhanced Engine Response for  
Emergency Operations

Robust Engine Control

Model-Based Engine Control

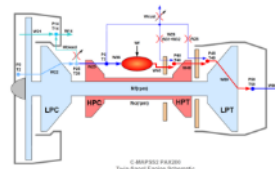
V&V of Advanced Controls

### High Speed Propulsion

Aero-Propulso-Servo Elasticity for  
Supersonic Propulsion System

Mode Transition Management for Air-  
Breathing Hypersonic Propulsion

## Health Management



### Propulsion & Power Systems

Gas Path Health Management

Sensor Selection

Sensor Data Qualification

Fault Modeling and Diagnostics

Model-Based Engine Simulation for  
Engine Test, Calibration and  
Performance Analyses

## Current NASA Programs

### Aeronautics Research Mission

Advanced Air Vehicle

Airspace Operations and Safety

Transformative Aeronautics Concepts

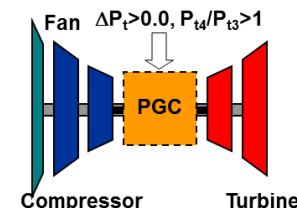
### Human Exploration and Operations Mission

Space Launch System

SCAN

Orion

## Advanced Propulsion Concepts



### Unsteady Propulsion

Pulse Detonation Engine

Pressure Gain Combustion

## Communications

### Integrated Radio and Optical Comm

Spacecraft Attitude Estimation

Spacecraft Structural Dynamics

## Software Tools

### Engine Modeling & Control

C-MAPSS (Commercial Modular Aero  
Propulsion System Simulation)

C-MAPSS40k (40,000 lb Thrust Engine)

T-MATS (Tool for Modeling and Analysis  
of Thermodynamic Systems)

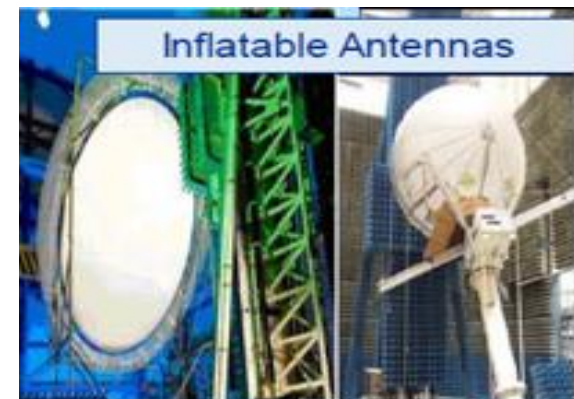
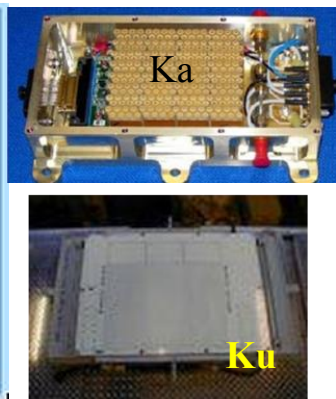
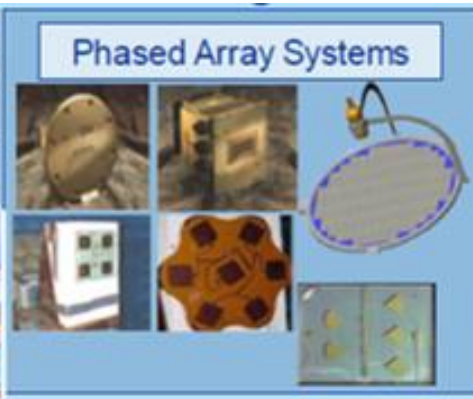
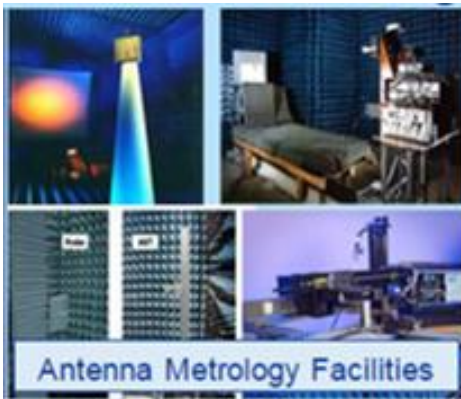
Combustion Instability Simulation



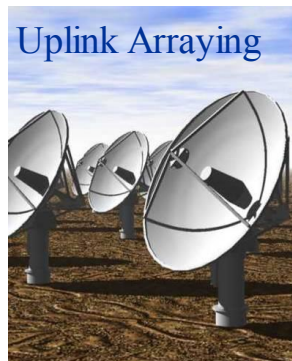
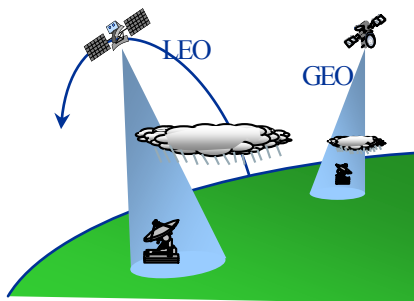


# Specific Technology Areas of Interest

# Advanced RF Antenna and Optical Technologies



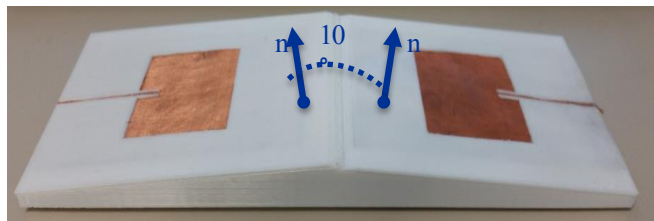
Antennas/Propagation



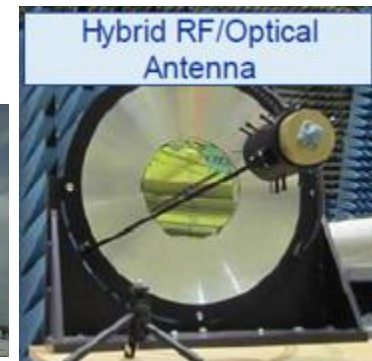
Shape Memory Polymers Antennas



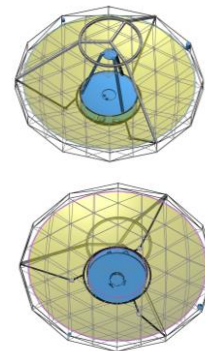
3-D Printed Antennas for Cubesats



SCaN Testbed Ground Station



Teletenna Concept



# Advanced RF Antenna and Optical Technologies

## Areas of Interest

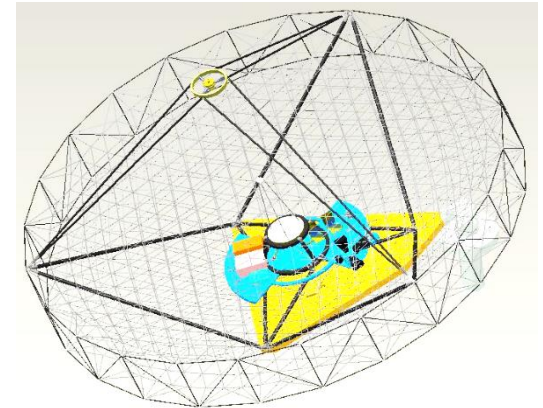
- Flight and ground antennas providing larger effective apertures than those currently in operation, with high efficiency but lower mass per unit area and accurate pointing.
- Novel materials, design, and manufacturing methods that enable lower mass, greater efficiency, and greater control of fields across the antenna aperture.
- Game-changing advances in component technologies that could enable significant advances in antenna array performance and enable alternate, higher-performance architectures
- Ka-band multiple-access phased arrays for NASA's Next Generation Communication and Navigation Architecture Systems (i.e., TDRSS follow-on relay and user terminals)
- High-performance electronically-steered antennas required for a dedicated communications relay spacecraft with multiple simultaneous connections, advanced multifunction antennas to support science missions that utilize a multifunction antenna to both communicate and conduct science.
- Antennas that are reconfigurable in frequency, polarization, and radiation pattern that reduce the number of antennas needed to meet the communication requirements
- Arrays of optical telescopes as an option to building large monolithic telescopes
- Light weight precision mirror technologies for space applications
- Novel high efficiency single photon counting detector systems

# Example of Optical Technology Need: Novel Optical Communications Architectures

**Goal:** Develop futuristic deep-space optical communications terminals for space and ground systems

**Objective:** Investigate hybrid microwave and optical teletenna systems for deep space communications and explore alternative to single monolithic earth-based terminals.

**Challenge:** Minimizing hybrid system mass; implementing precision beaconless pointing; realizing vibration isolation to support micro-radian beam pointing; minimizing ground array cost relative to single monolithic telescope.



**Benefit:** Enhancing data rate from Mars to Earth from the current 6 Mbps to over 250 Mbps and minimizing the capital investment needed to support the ground infrastructure to enable that link.

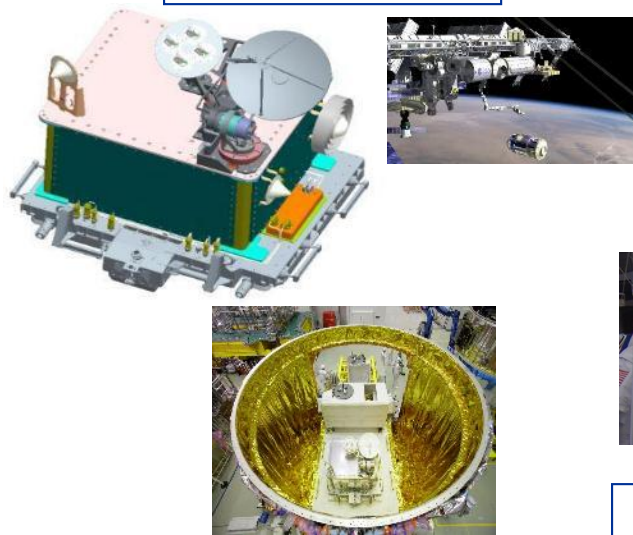
**State of Art Technology Readiness Level (TRL): 3**

**Technology Performance Goal TRL: 6**

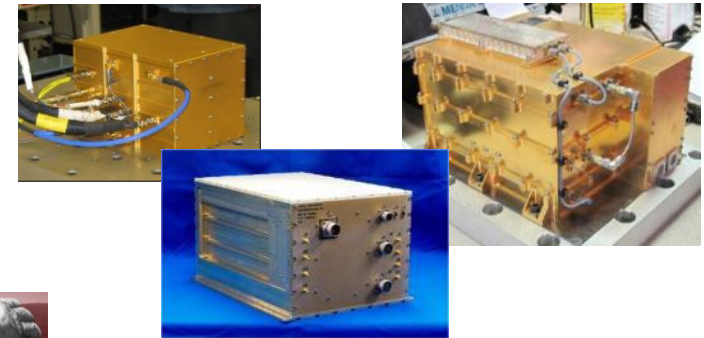


# Cognitive Radio and Signal Processing Technologies

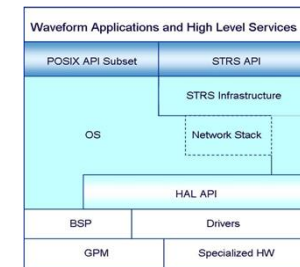
SCaN Testbed



Software Defined/Cognitive Radios



AES/EVA Radio/Integrated Audio



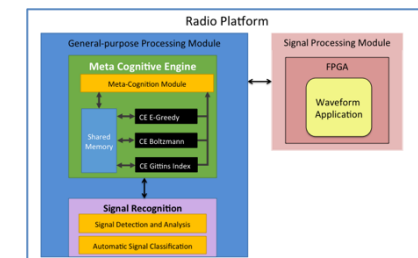
Combined Communications/Imaging



iROC Flexible Digital Core



Space Telecommunication Radio System (STRS) Architecture



Cognitive Engine Algorithms



# Cognitive Radio and Signal Processing Technologies

## Goal

To improve the state of the user platform (spacecraft/aircraft) to maximize data return, enable substantial efficiencies, or adapt to unplanned scenarios through the use of cognitive systems. Cognitive systems and autonomy have the potential to improve system performance, increase data volume return, improve data transmission efficiency, and reduce user burden to improve science return from NASA missions. Cognitive systems will sense, detect, adapt, and learn from its environment to improve the communications/navigation capabilities of the user platforms.

## Areas of Interest

- Cognitive engine (algorithm) and component development to demonstrate new capability in sensing and adapting to the radio/mission environment
- Introduce changes in physical layer (PHY) data rate, modulation, and coding, media access control layer (MAC) for new protocols and cognitive engines to negotiate changes between nodes and throughout the network, learning opportunities and techniques, and networking and application layers (and across layers) to adjust to signal conditions, efficiently using links for telemetry, video, adaptive and intelligent routing, etc.

# Cognitive Radio and Signal Processing Technologies

## Areas of Interest

- System wide distributed intelligence of cognitive and intelligent applications - system wide effects on decisions made by one or more communication/navigation elements, how to handle unexpected or undesired decisions
- Flexible data rate, modulation, or frequencies between nodes of satellites, utilizing space and ground network stations and multiple access techniques that optimize connectivity and throughput while minimizing onboard data storage and interference
- Signal processing platforms, adaptive front ends for RF or optical communications with cognitive or intelligent applications to provide needed capability while minimizing on-board resources and cost.
- Precise autonomous navigation and pointing techniques to minimize pointing loss and to coordinate multiple autonomous activities with cognitive radio systems that can continuously maximize data return via both multiple beam GEO relays and direct to ground links.

# Example of Cognitive Technology Needs: Adaptive Coding and Modulation DVB-S2

## Previous approaches for Space Applications

- NASA networks are fixed coding & modulation
- Worst case link margin used to guarantee nominal operations,, leading to overdesigned systems, and non-optimal utilization
- Increasing capability requires proportionally larger systems

## New Method:

- Coding and modulation (data rate) can be varied based on link conditions, applicable to all space networks (SN, DSN, NEN)
- Leverage existing standards (e.g. DVB-S2, CCSDS AOS OCF)
- Apply cognitive systems to sense, detect, classify, learn, and adapt to time-varying communication environment.

## Benefits:

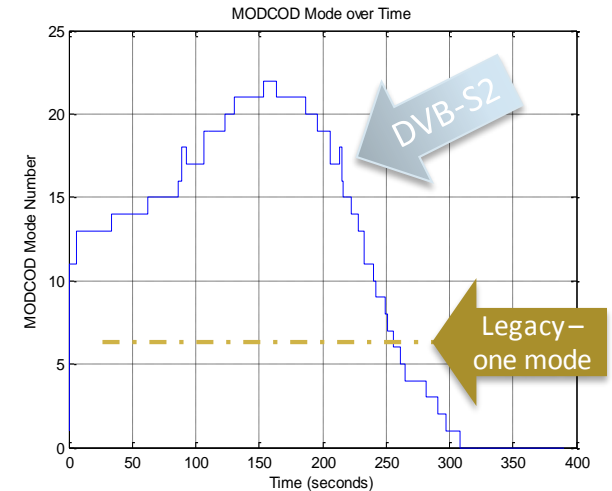
- Increased data volume return and efficient use of communication link and spectrum
- Communications more robust and resilient to unpredicted conditions (e.g. interference)
- Enables increased autonomy

## Return on Investment

- **3X** data throughput increase
- Access time per user services/infrastructure
- Reduced SWaP, operations complexity, and cost
- Increased system contingency management capability

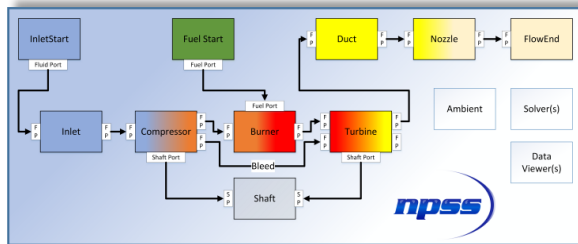
## Technology Infusion Plan

- Collaboration with SN on DVB-S2 for operations
- Applications will go into STRS repository for mission reuse
- Foundation for cognitive/intelligent systems



Legacy Mode (OQPSK, Conv&RS, 5 MSym)  
- average throughput of **3 Mbps**  
DVB-S2 Mode (5 MSym)  
- average throughput of **9 Mbps**

# Control, Simulation, & Embedded HW Technologies



Engine Design – **Steady State** Model

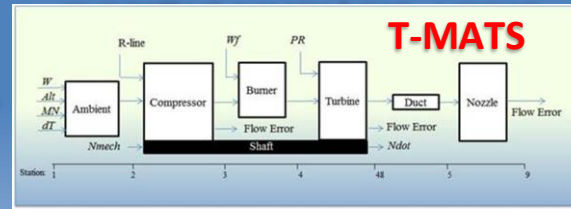


GE GenX engine

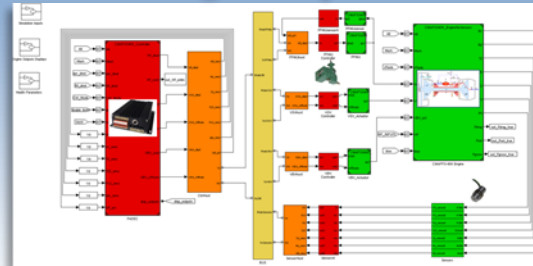
**Iterative Process**



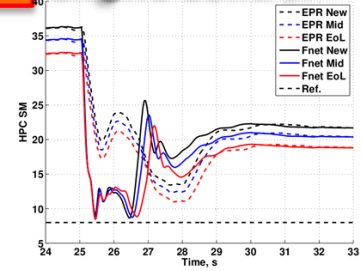
## Design/Analysis Tools



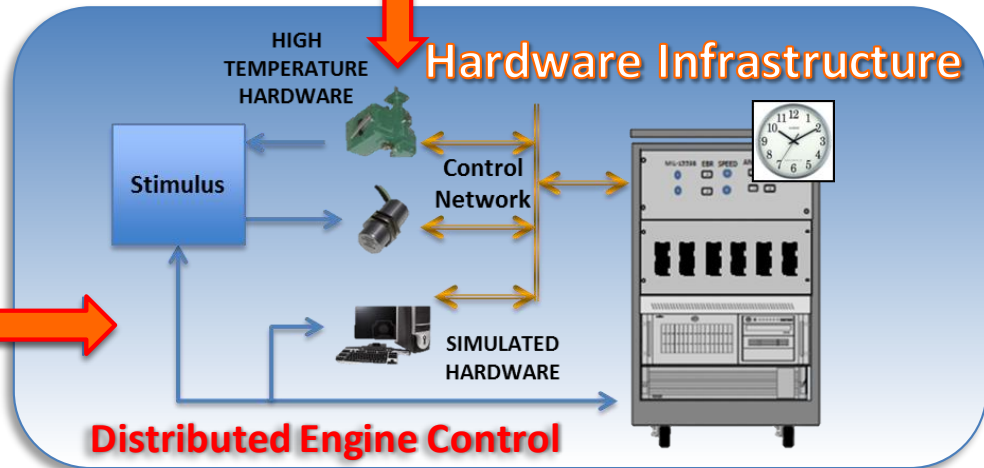
Control Design – **Dynamic** Model



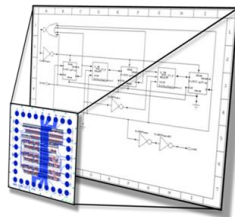
## Model Based Engine Control



## Hardware Infrastructure



**NASA High Temperature Silicon Carbide Electronics**



# Control, Simulation, & Embedded HW Technologies

## Areas of Interest

- Improved understanding of the information contained in the engine gas path related to system performance and safety.
- Improved sensing of spatial and temporal information in the engine gas path to extract information.
- Improved high temperature electronics to enable close coupling of the transducer to signal processing and digital data reduction functions.
- High speed, secure, reliable, local area networks in a high temperature environment to ensure deterministic distributed data flow and stable system control.
- Access to sufficient on-board computational resources to collect and process wide bandwidth system sensory data, process multivariable control algorithms, and evaluate control output relative to real-time model-based dynamic system simulation.
- Improved computational efficiency of complex multivariable control algorithms.
- Improved convergence and accuracy of real-time, on-board, dynamic engine system simulation.
- Improved modeling of engine system deterioration.
- Improved responsiveness and accuracy of engine system actuators.
- Improved fidelity of engine system simulation tools to enable quantitative evaluation of engine control architecture and engine system relative to constraints, performance and safety impact.
- More rapid control design process to enable timely input that impacts engine design process.

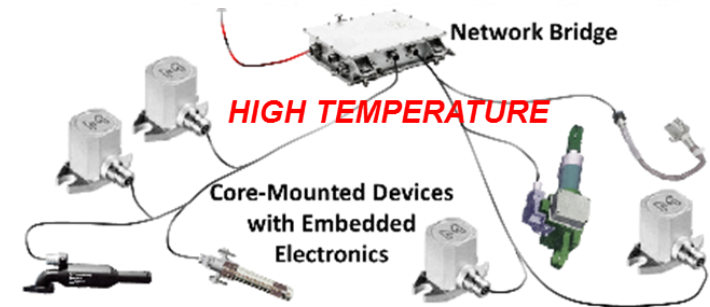
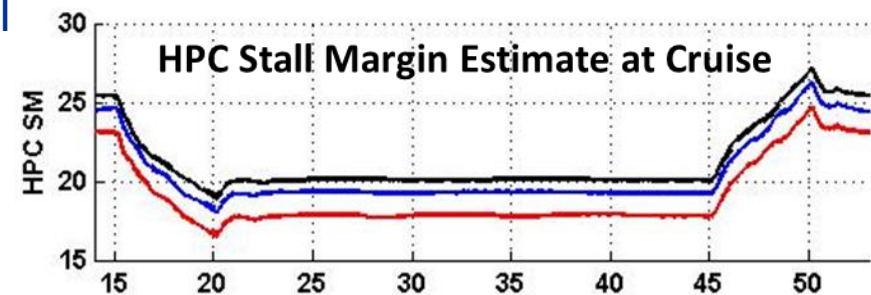
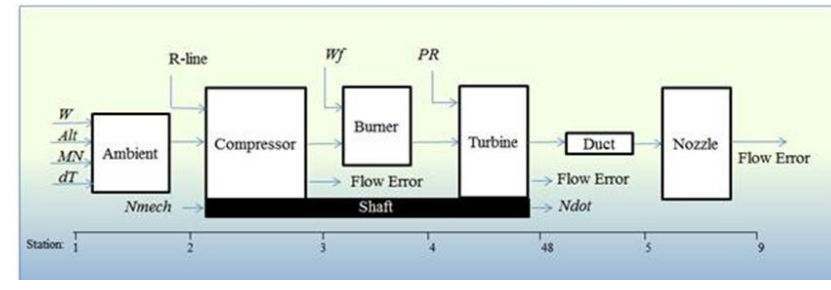


# Example of Engine Control Technology Need: Control System Impact on Engine Design

**Goal:** Demonstrate the capability of the control system to trade mechanical engine design margin for safe engine system performance improvement.

**Objective:** Investigate model-based control algorithms to precisely estimate system stability margin and performance characteristics in order to safely take advantage of unused engine capability.

**Challenge:** Coordinate a multidisciplinary investigation that couples steady-state engine design with dynamic control modeling and evaluates the outcome in terms of control hardware capabilities and architecture.



**Benefit:** Safely improve engine responsiveness and reduce fuel burn while developing design tools that have the capability to